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TECHNICAL MEMORANDUM

HIGH PRESSURE GAS STORAGE SYSTEM CONSUMABLES ANALYSES  
FOR ALT FLIGHTS FREE FLIGHT 1 AND FREE FLIGHT 6

by

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## 1. INTRODUCTION

This memorandum provides consumables analyses for the High Pressure Gas Storage (HPGS) oxygen ( $O_2$ ) and hydrogen ( $H_2$ ) reactant systems for Orbiter Vehicle (OV) 101 Approach and Landing Tests (ALT), for two flights, Free Flight 1 and Free Flight 6. The consumables analyses are based on average power data obtained from reference 1. The required system and mission data updates were made in order to perform the analyses, notably the thermal environment profiles of the reactant storage cylinders and the power profile for the Electrical Power Subsystem (EPS). No mission-dependent environment profiles were provided; therefore, the nominal Free Flight mission profile in reference 1 was used to generate environment profiles for Free Flights 1 and 6.

## 2. ABBREVIATIONS AND ACRONYMS

ALT	Approach and Landing Test
EPS	Electrical Power Subsystem
F/F	Free Flight
H <sub>2</sub>	Hydrogen
HPGS	High Pressure Gas Storage
lb/ft <sup>3</sup>	Pound per foot cubed
lbm	Pound mass
O <sub>2</sub>	Oxygen
OV	Orbiter Vehicle
PSIA	Pounds per square inch absolute
RI	Rockwell International

### 3. SYSTEM PERFORMANCE DATA AND MODELING TECHNIQUES

#### 3.1 SYSTEM PERFORMANCE DATA

Specific fuel consumptions for  $H_2$  and  $O_2$  are based on EPS analyses data obtained from reference 1. The output from the EPS analyses was provided in the form of tables. Data values were read from these tables and taken as input for the HPGS model.

Nominal tank volumes for  $H_2$  and  $O_2$  were taken from reference 2. The total tank volume for the  $H_2$  and  $O_2$  reactant systems then is a function of the number of tanks in each  $O_2$  and  $H_2$  reactant system (primary and secondary).

The pressure limits for switching from primary system to secondary system were set at 800 psia ( $O_2$  primary) and 200 psia ( $H_2$  primary). The secondary system pressure limits were set at 200 psia for both  $O_2$  and  $H_2$ . If secondary pressure limits are reached, program analysis terminates.

#### 3.2 MODELING ASSUMPTIONS

##### 3.2.1 OXYGEN

Oxygen tank pressure and temperature were initialized at 55°F/2134.0 psia (cold case). The pressure and temperature values of  $O_2$  and  $H_2$ , as will be described later, were chosen to match the cold case situation (worst case). Cold case is defined as an initial environment bay temperature of 55°F with a minimum of 0°F inflight temperature.

Total reactant loaded for each the primary and secondary systems for  $O_2$  and  $H_2$  were computed as a function of the initial pressure, temperature, and tank volume. The computations for  $O_2$  revealed load values of approximately 92.788 lbm for the  $O_2$  primary system and 23.197 lbm for the  $O_2$  secondary system.

### 3.2.2 HYDROGEN

Hydrogen tank pressure and temperature were initialized at 55°F/2370.0 psia (cold case).

The computations for  $H_2$  reactant loaded revealed load values of approximately 8.176 lbm for  $H_2$  primary system and 2.725 lbm for the  $H_2$  secondary system.

#### 4. REFERENCE MISSION CONSUMABLES ANALYSES

The major time/events for the Free Flights are shown in tables I through III (ref. 3).

##### 4.1 FREE FLIGHT NUMBER 1

###### 4.1.1 TIMELINE AND ASSUMPTIONS

The EPS timeline for the Free Flight 1 mission analysis was taken from the power profile tables shown in reference 1. The tables were read and average power loads of 15.75 kw and 17.5 kw were used. 15.75 kw were used from T-83 minutes (transfer to internal power) to T-0 (takeoff). 17.5 Kw were used from T-0 to orbiter powerdown (T + 65 for F/F 1).

The thermal environment profiles used for the analyses (both F/F 1 and F/F 6) were generated by performing extrapolations on the thermal environment profile for a nominal Free Flight mission provided in reference 1.

###### 4.1.2 F/F 1 CONSUMABLES ANALYSIS RESULTS

Tables IV and V show the primary and secondary  $O_2$  and  $H_2$  parameters at initialization and the end of F/F 1 mission analysis. Figures 1 through 7 show quantity consumed, pressure, temperature and thermal environment plot data for the F/F 1 mission analysis.

The output data tapes from the F/F 1 analysis are:

<u>Tape</u>	<u>Tape Number</u>
HPGS Plot Tape	X18407
Calcomp Plot Tape	X21322

The data provided for the F/F 1 analysis is also representative for F/F 2 through 5.

TABLE I. - LIST OF PREFLIGHT MAJOR EVENTS - GENERIC FOR ALL FLIGHTS

<u>Time (minutes)</u>	<u>Event</u>
T-300	Power on Computer/time initialization Operations 0 Inertial measuring unit preflight 0 Systems activation and checkout
T-110	Operations 2
T-104	Crew ingress
T-92	Transfer to onboard reactants
T-83*	Transfer to internal power
T-82	Transfer to internal cooling
T-80	Ground support equipment umbilical pullout
T-62	Orbiter Shuttle carrier aircraft move from mating/ demating device
T-60	Ground/shuttle carrier aircraft move from mating/ demating device
T-56	Orbiter/shuttle carrier aircraft tow to National Aeronautics and Space Administration ramp
T-44	Orbiter/shuttle carrier aircraft arrive at National Aeronautics and Space Administration ramp
T-42	Shuttle carrier aircraft engines start
T-32	Shuttle carrier aircraft begin taxi to runway
T-30	Flight control system mode switch checks
T-12	Shuttle carrier aircraft arrive at runway
T-11	Activate auxiliary power unit/hydraulics system 2 & 3
T-9	Flight control system deflection checks
T-0	Shuttle carrier aircraft brake release - takeoff and climbout

\*Start time of mission analyses.

TABLE II-LIST OF MAJOR EVENTS/TIMES FOR FREE FLIGHTS 1 THROUGH 5

<u>Event</u>	<u>Time (minutes)</u>
SCA Brake Release - Takeoff and Climbout	T=0
Cabin Pressurization Management	T+3
Activate APU/HYD System 1 Deactivate APU/HYD System 2	T+20
FCS Inflight Checkout	T+22
SCA Start Special Rated Thrust	T+36
Activate APU/HYD System 2	T+37
State Vector Update (if required)	T+40
Preseparation Checks	T+44
SCA Pushover	T+45
SCA Orbiter Separation	T+46
Orbiter Landing	T+51
Deactivate APU/HYD Systems	T+55
Orbiter Powerdown	T+65
Orbiter Crew Egress	T+75

Note for F/F 5 only:

Add 6 minutes to crew egress time



TABLE III-LIST OF MAJOR EVENTS/TIMES FOR FREE FLIGHTS 6, 7, and 8

<u>Event</u>	<u>Time (minutes)</u>
SCA Brake Release Takeoff and Climbout	T=0
Cabin Pressurization Management	T+3
Activate APU/HYD System 1 Deactivate APU/HYD System 2	T+16
FCS Inflight Checkout	T+17
SCA Start Special Rated Thrust	T+30
Activate APU/HYD System 2	T+32
State Vector Update (if required)	T+35
Preseparation Checks	T+38
SCA Pushover	T+40
SCA Orbiter Separation	T+41
Orbiter Landing	T+43
Deactivate APU/HYD Systems	T+46
Orbiter Powerdown	T+57
Orbiter Crew Egress	T+67

TABLE IV-INPUT PARAMETERS FOR F/F 1 COLD CASE (55°F)

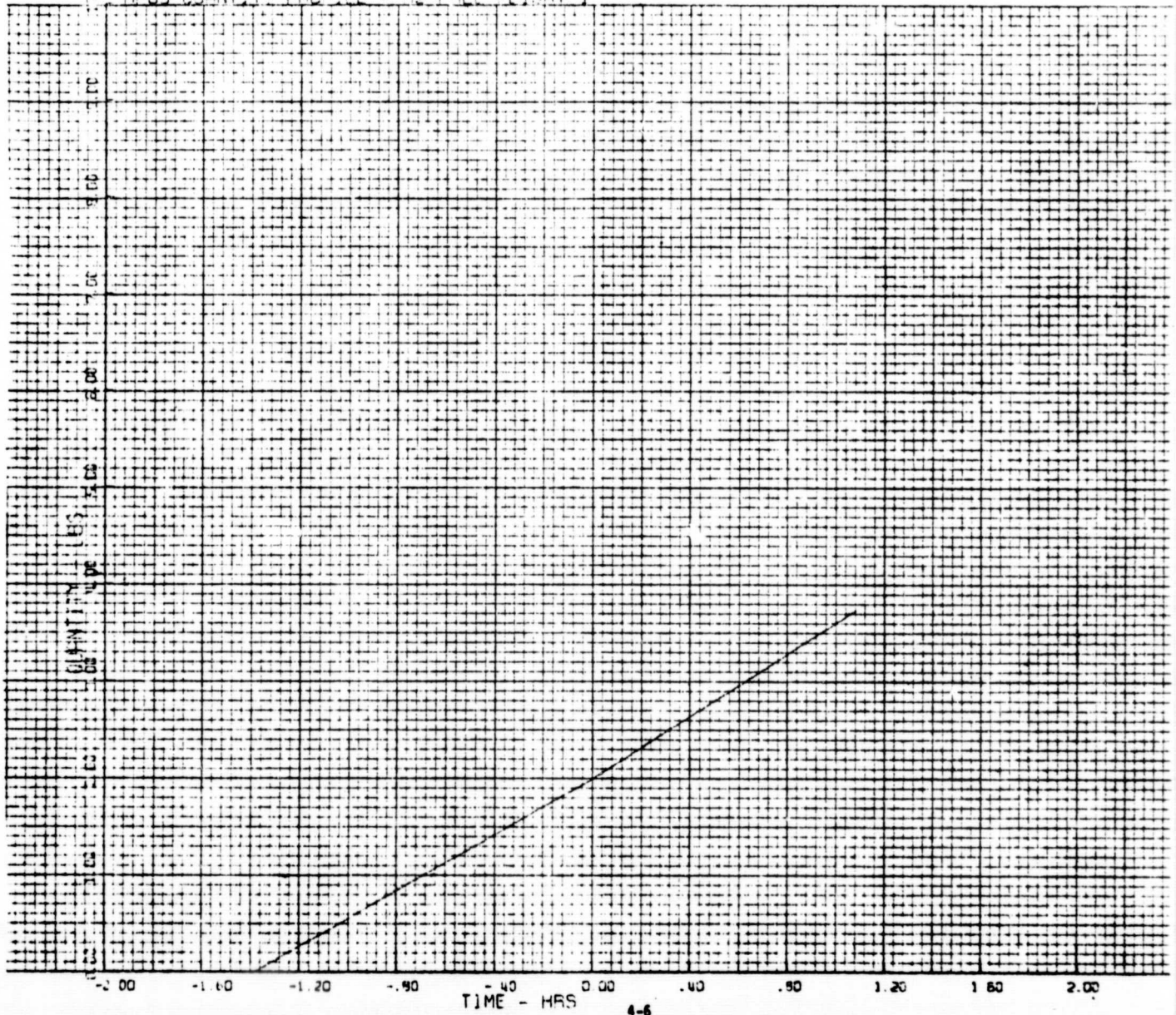
Parameter	Primary O <sub>2</sub>	Secondary O <sub>2</sub>	Primary H <sub>2</sub>	Secondary H <sub>2</sub>
Quantity remaining, lb	92.788	23.197	8.176	2.725
Temperature, °F	55.0	55.0	55.0	55.0
Pressure, psia	2134.0	2134.0	2370.0	2370.0
Density, lb/ft <sup>3</sup>	13.361	13.361	.785	.785
Quantity used, lb	0.0	0.0	0.0	0.0

TABLE V-FINAL RESULTS FOR F/F 1 COLD CASE

Parameter	Primary O <sub>2</sub>	Secondary O <sub>2</sub>	Primary H <sub>2</sub>	Secondary H <sub>2</sub>
Quantity remaining, lb	63.414	23.181	4.444	2.723
Temperature, °F	30.722	39.014	27.992	38.943
Pressure, psia	1385.379	2036.822	1163.933	2291.673
Density, lb/ft <sup>3</sup>	9.132	13.352	.427	.784
Quantity used, lb	29.373	0.0	3.731	0.0

Figure 1

HPGS QUANTITY PROFILE - R2 FREE FLIGHT 1



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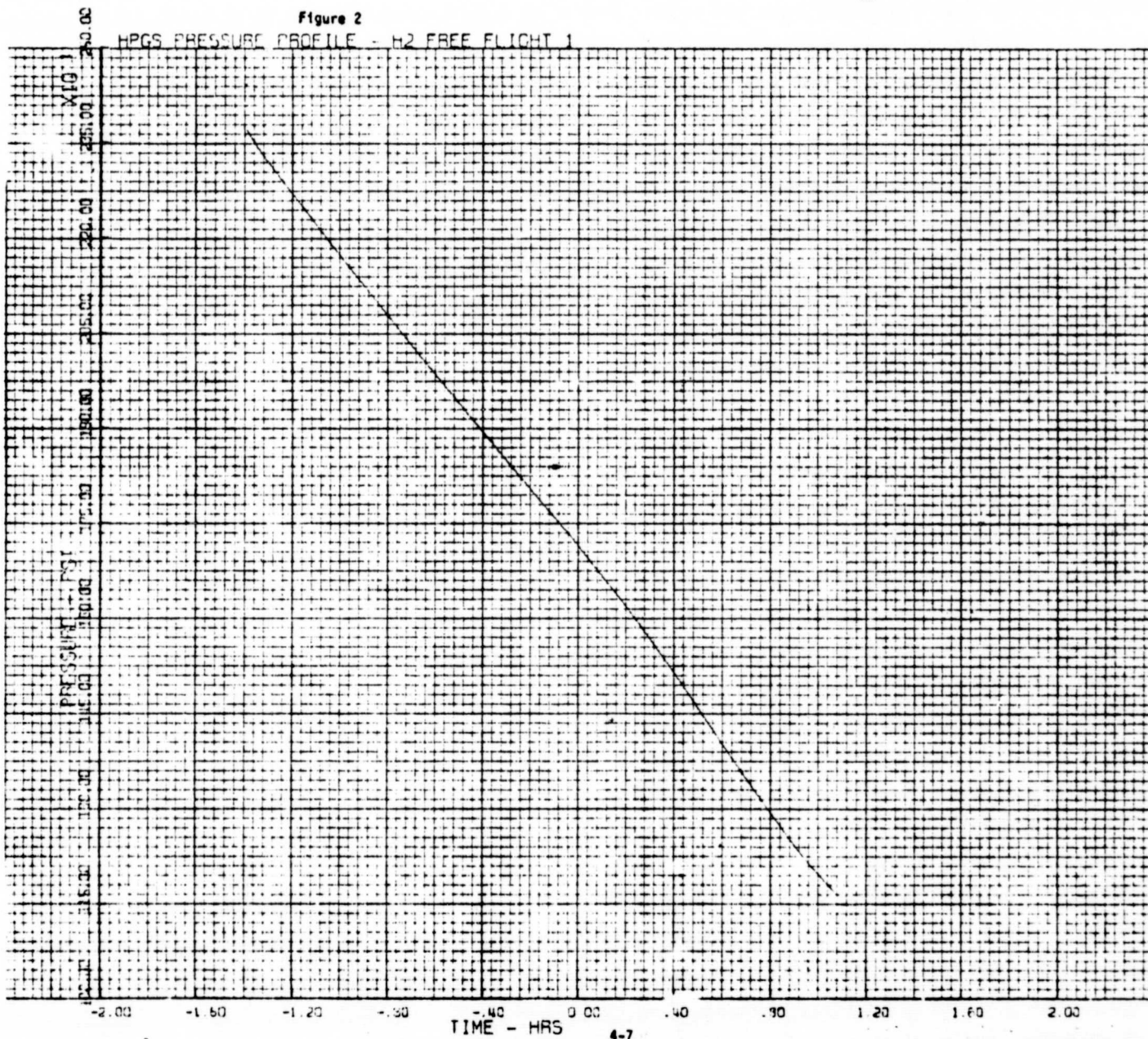
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Figure 2

HPGS PRESSURE PROFILE - H2 FREE FLIGHT 1



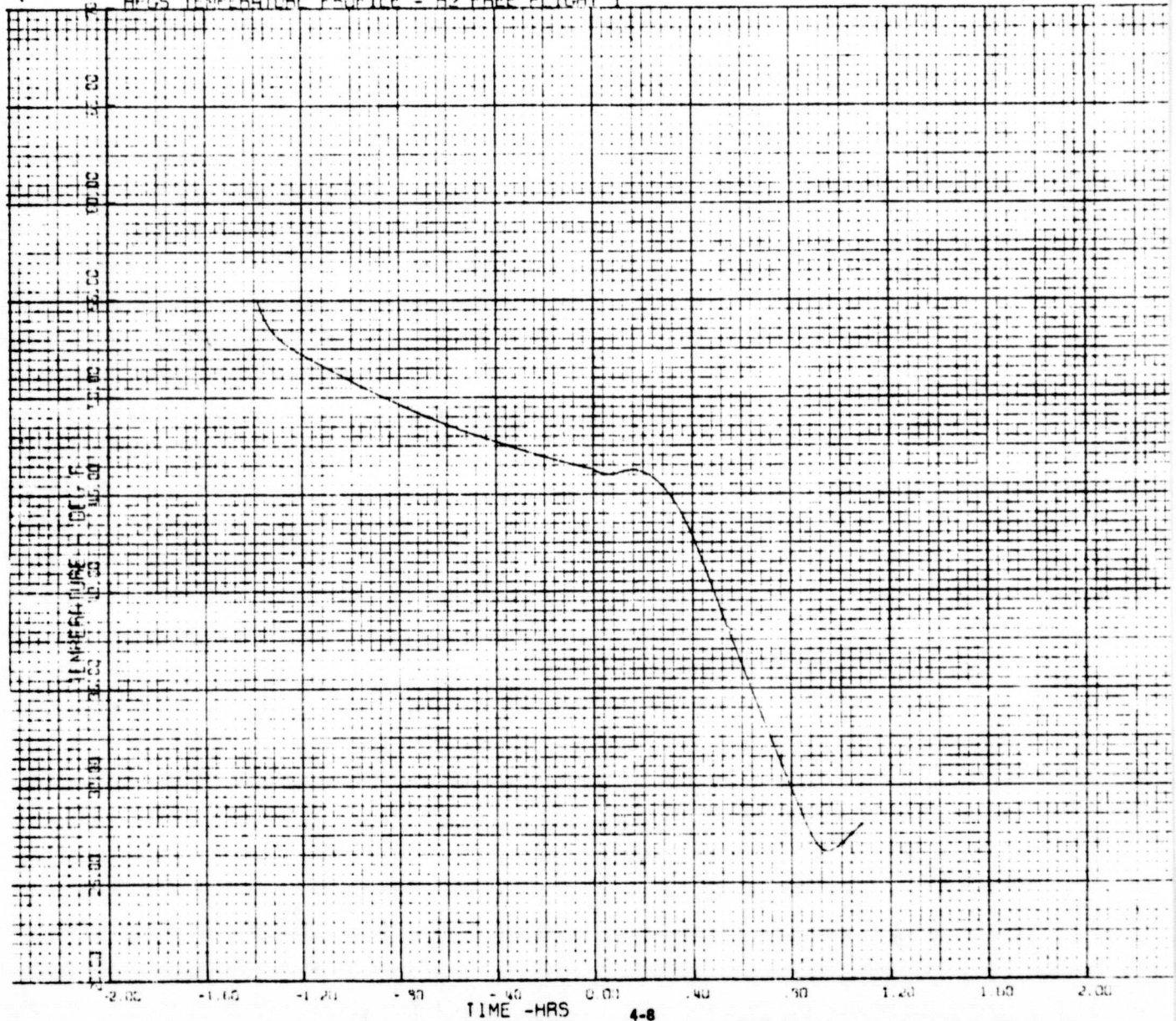
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Figure 3

HQGS TEMPERATURE PROFILE - H2 FREE FLIGHT 1



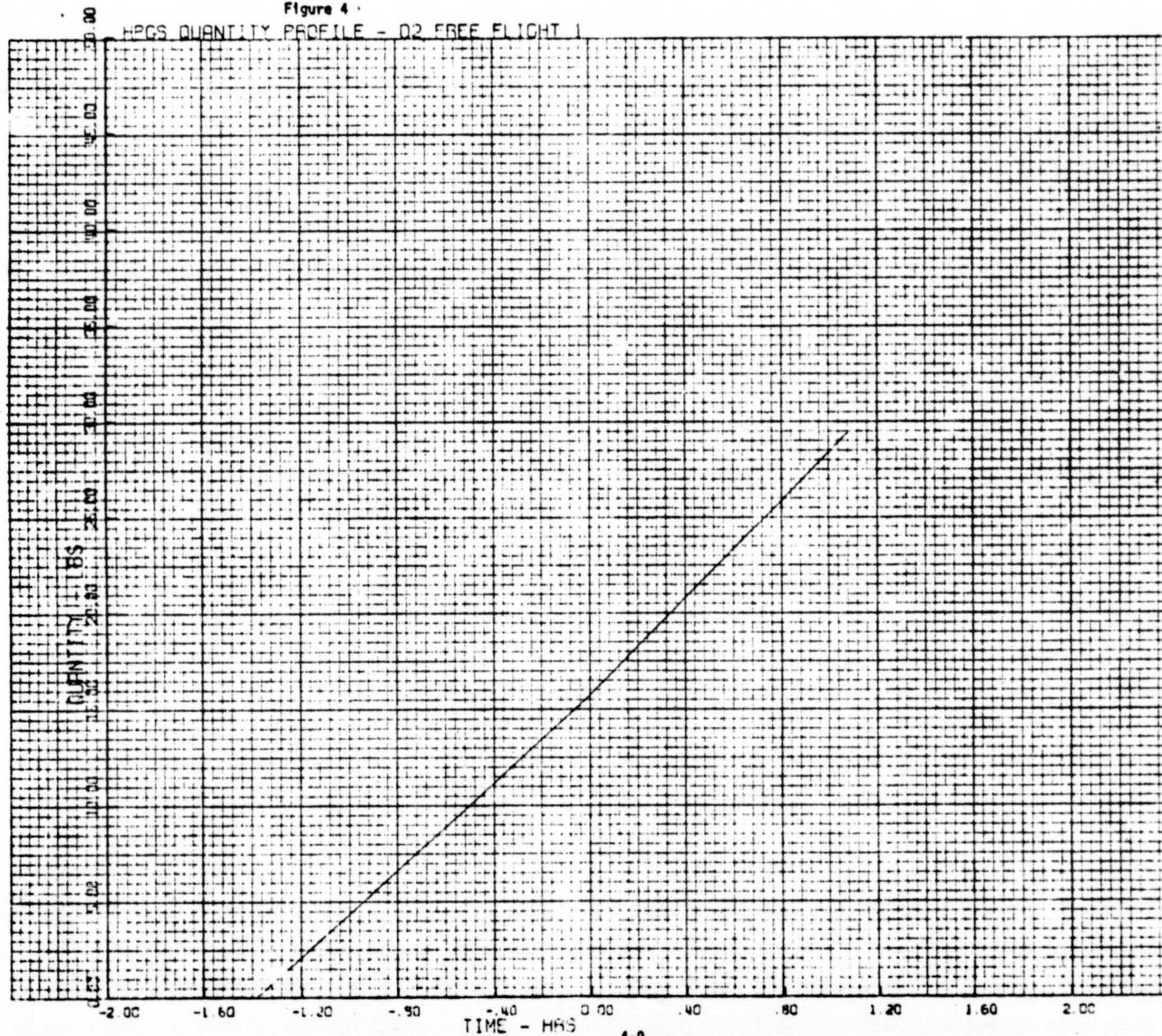
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Figure 4

HPS QUANTITY PROFILE - D2 FREE FLIGHT 1



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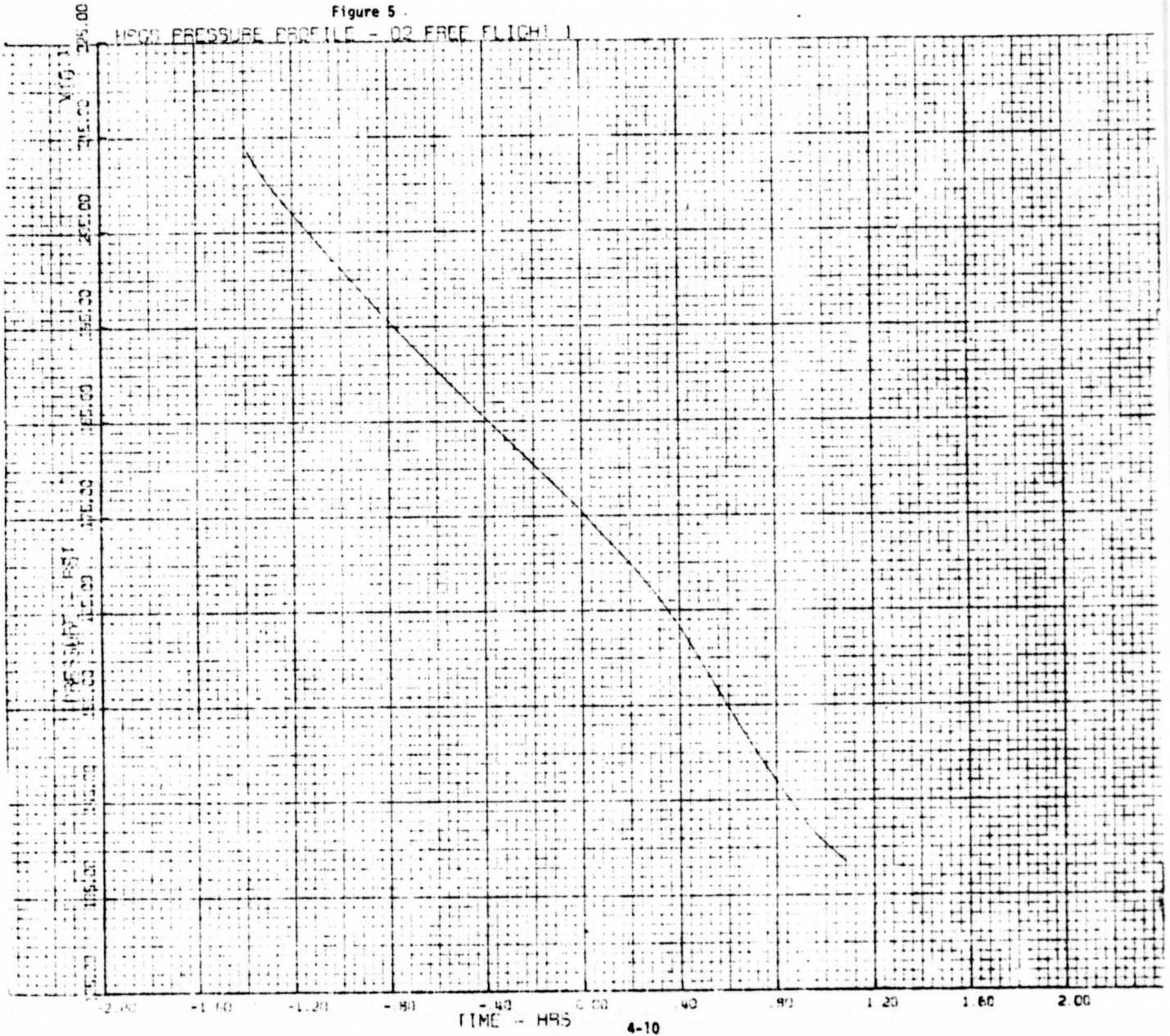
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Figure 5

HPCO PRESSURE PROFILE - Q2 FREE FLIGHT



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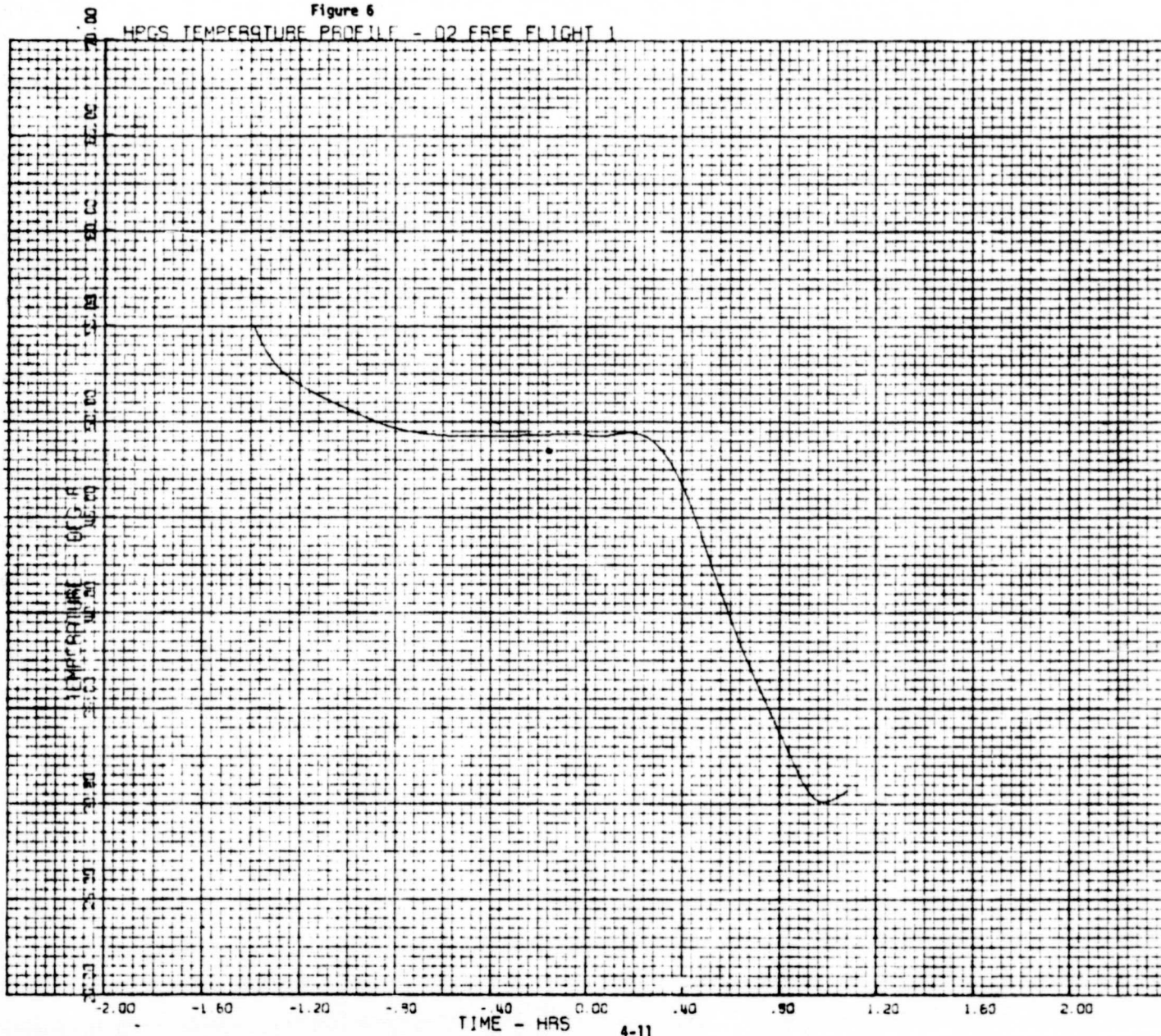
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Figure 6

HPGS TEMPERATURE PROFILE - D2 FREE FLIGHT 1



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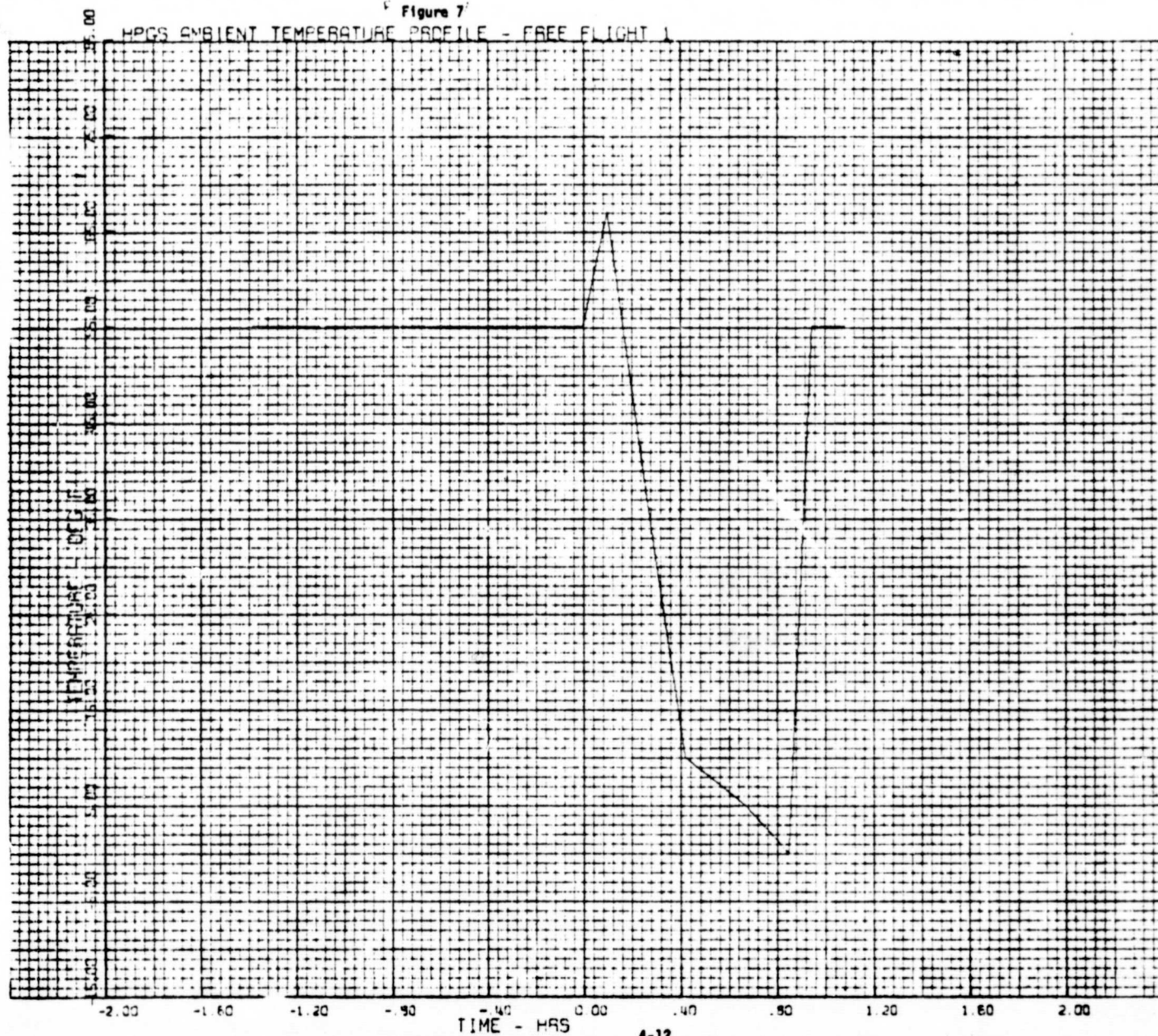
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Figure 7

HQGS AMBIENT TEMPERATURE PROFILE - FREE FLIGHT 1



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## 4.2 FREE FLIGHT NUMBER 6

### 4.2.1 TIMELINE AND ASSUMPTIONS

The EPS timeline for F/F 6 HPGS mission analysis was also taken from the tables provided in reference 1. The power loads for F/F 6 were also taken as 15.75 kw (T-83 minutes to T-0) and 17.5 kw for T-0 to orbiter powerdown. Orbiter powerdown for F/F 6 is T+57 minutes.

### 4.2.2 F/F 6 CONSUMABLES ANALYSIS

Tables VI and VII show the primary and secondary  $O_2$  and  $H_2$  parameters at initialization and at the end of the mission analysis. Figures 8 through 14 show the pressure, quantity consumed, temperature, and thermal environment plot data for the F/F 6 mission analysis.

The data provided for the F/F 6 analysis is also representative for Free Flights 7 and 8.

The output data tapes from the F/F 6 analysis are:

<u>Tape</u>	<u>Tape number</u>
HPGS Plot Tape	X20706
Calcomp Plot Tape	X19261

TABLE VI.-INPUT PARAMETERS FOR F/F 6 COLD CASE (55°)

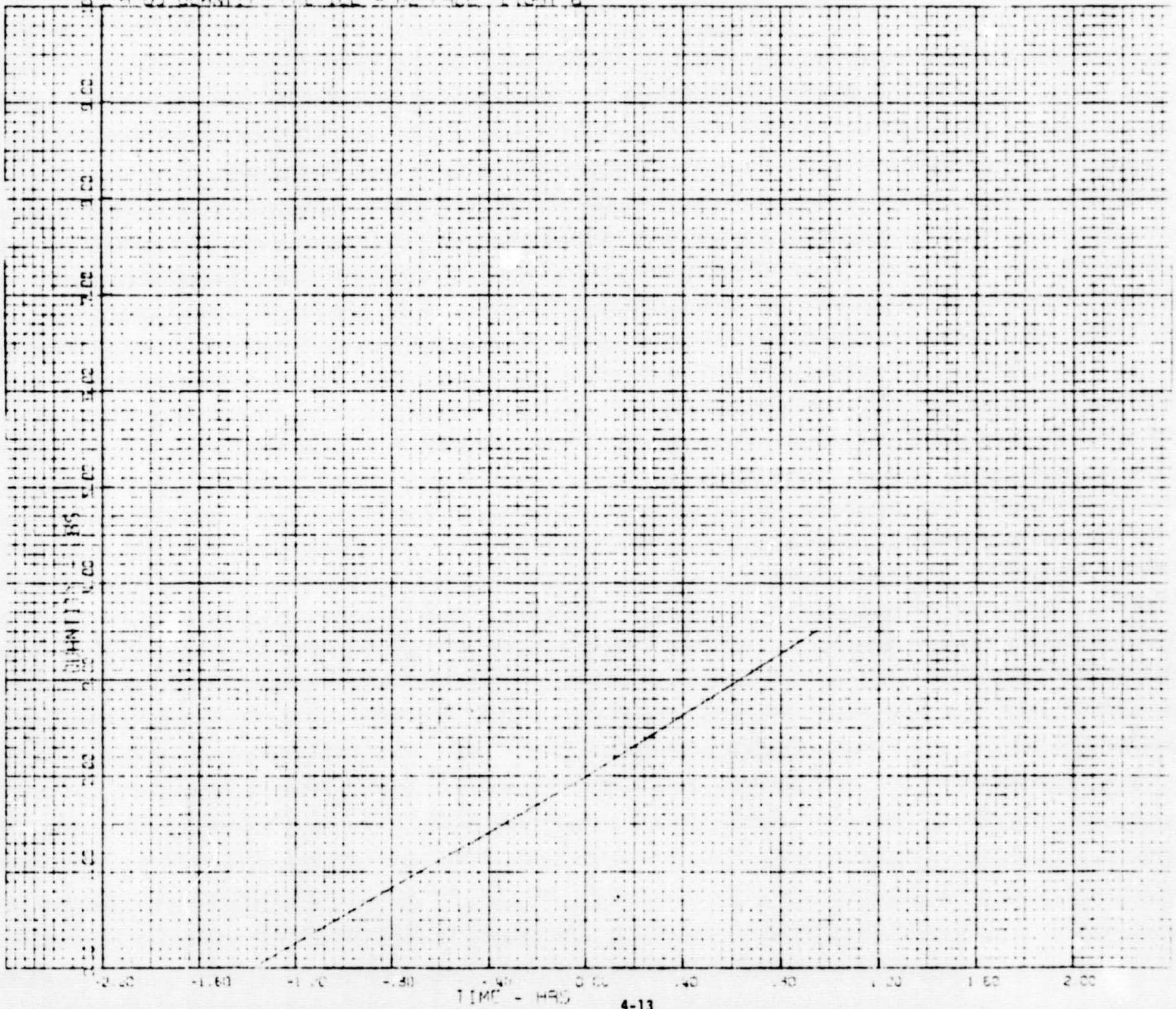
Parameter	Primary O <sub>2</sub>	Secondary O <sub>2</sub>	Primary H <sub>2</sub>	Secondary H <sub>2</sub>
Quantity remaining, lb	92.788	23.197	8.176	2.725
Temperature, °F	55.0	55.0	55.0	55.0
Pressure, psia	2134.0	2134.0	2370.0	2370.0
Density, lb/ft <sup>3</sup>	13.361	13.361	.785	.785
Quantity used, lb	0.0	0.0	0.0	0.0

TABLE VII.-FINAL RESULTS FOR F/F 6 COLD CASE

Parameter	Primary O <sub>2</sub>	Secondary O <sub>2</sub>	Primary H <sub>2</sub>	Secondary H <sub>2</sub>
Quantity remaining, lb	65.096	23.197	4.658	2.724
Temperature, °F	36.218	44.246	33.590	44.254
Pressure, psia	1441.418	2068.488	1237.310	2317.378
Density, lb/ft <sup>3</sup>	9.374	13.361	.447	.785
Quantity used, lb	27.692	0.0	3.518	0.0

Figure 8

PROB. QUANTITY PROFILE - NO FREE FLIGHT



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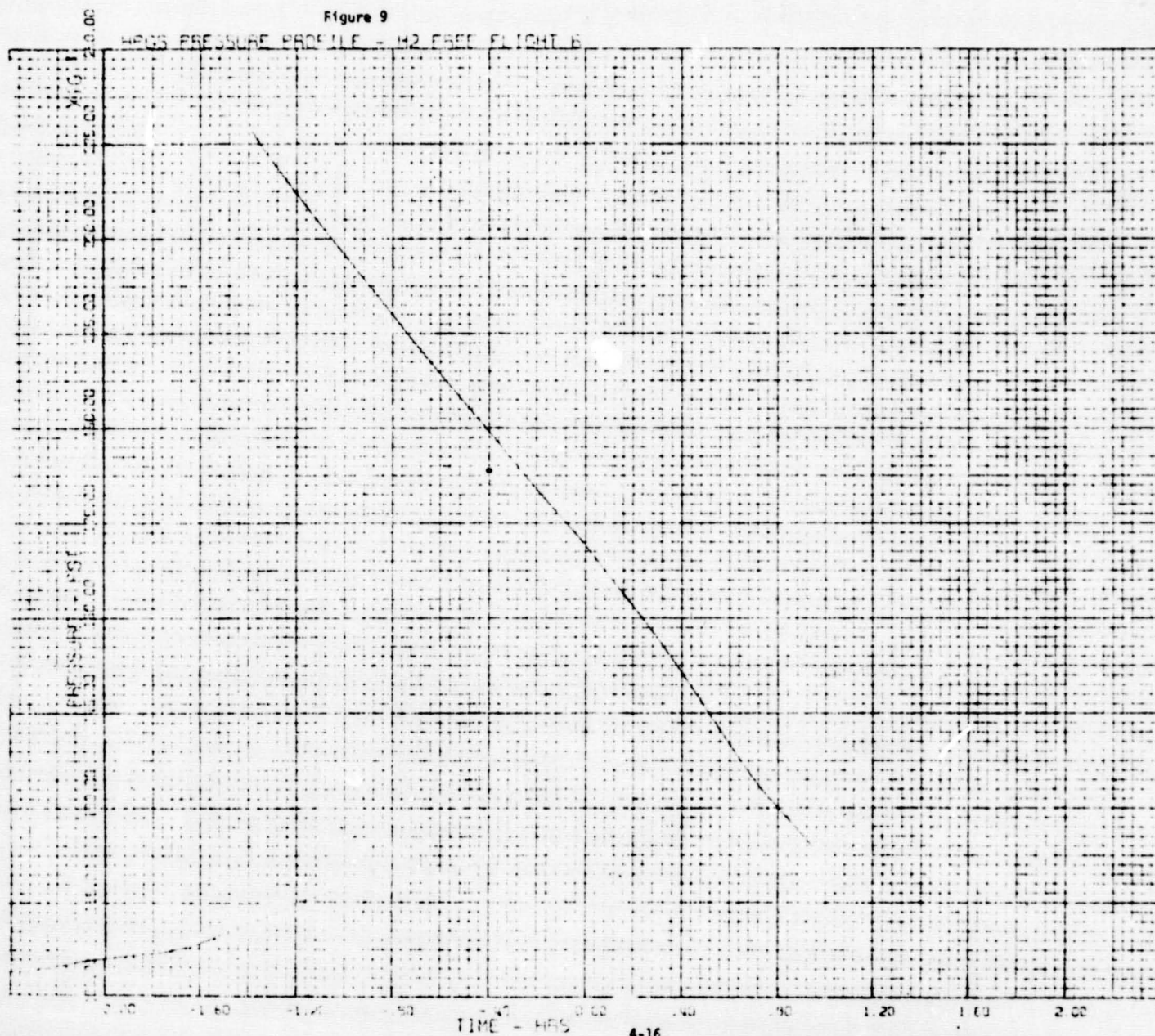
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Figure 9

HQGS PRESSURE PROFILE - H2 FREE FLIGHT 6



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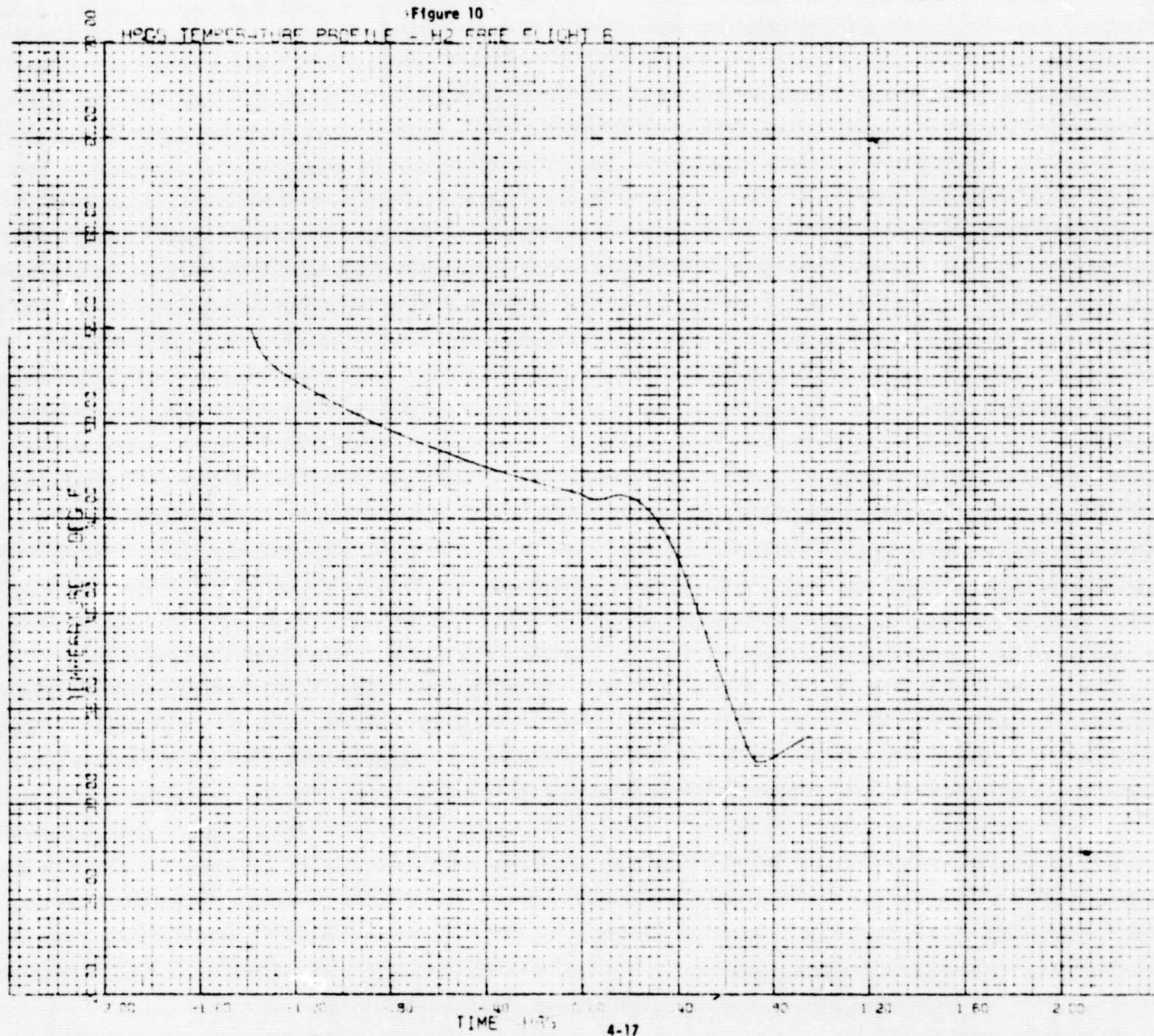
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Figure 10

HQS TEMPERATURE PROFILE - H2 FREE FLIGHT 6



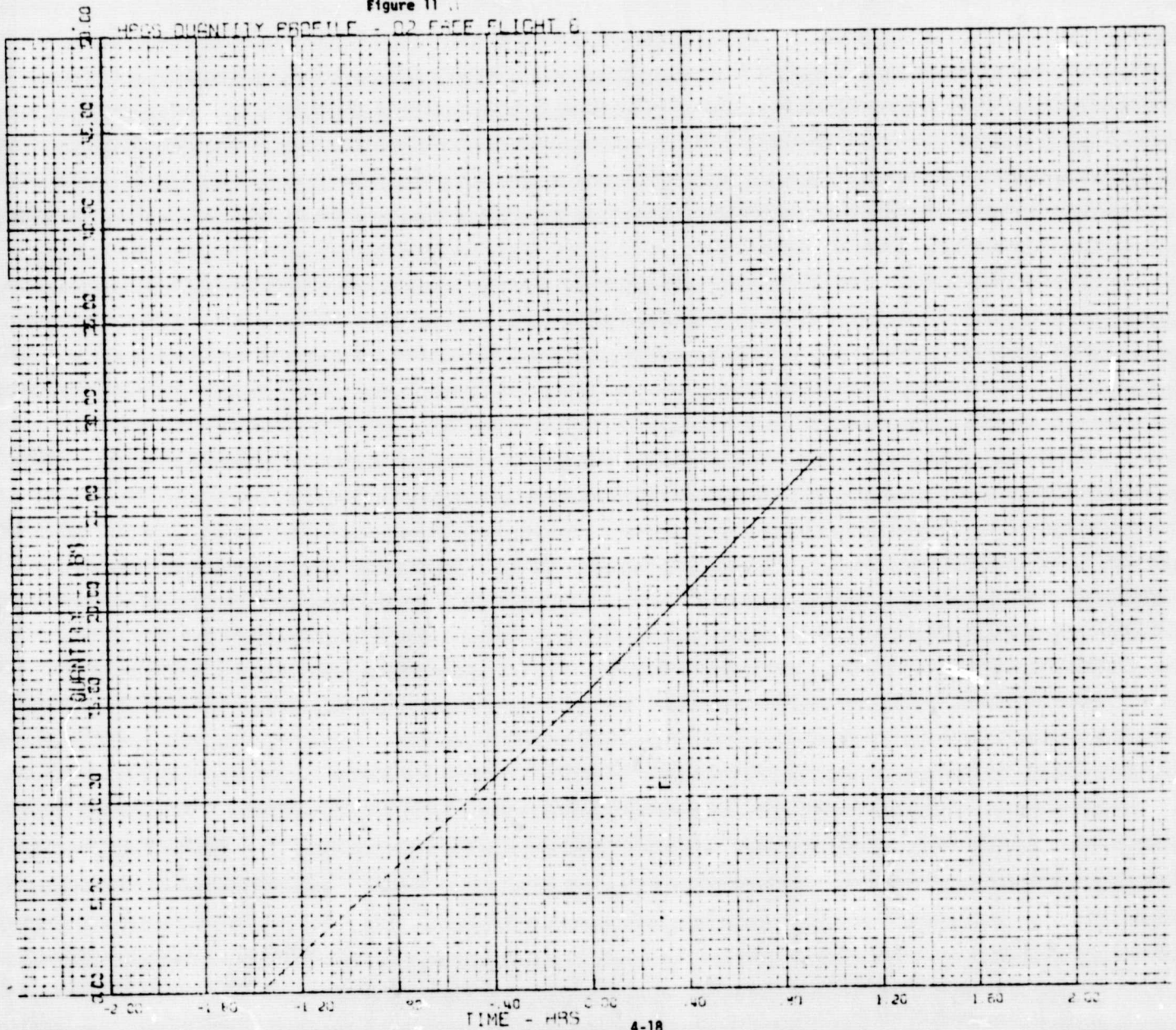
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Figure 11

HPGS DENSITY PROFILE - D2 FACE FLIGHT 8



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Figure 12

HQCS PRESSURE PROFILE - 02 FREE FLIGHT 6

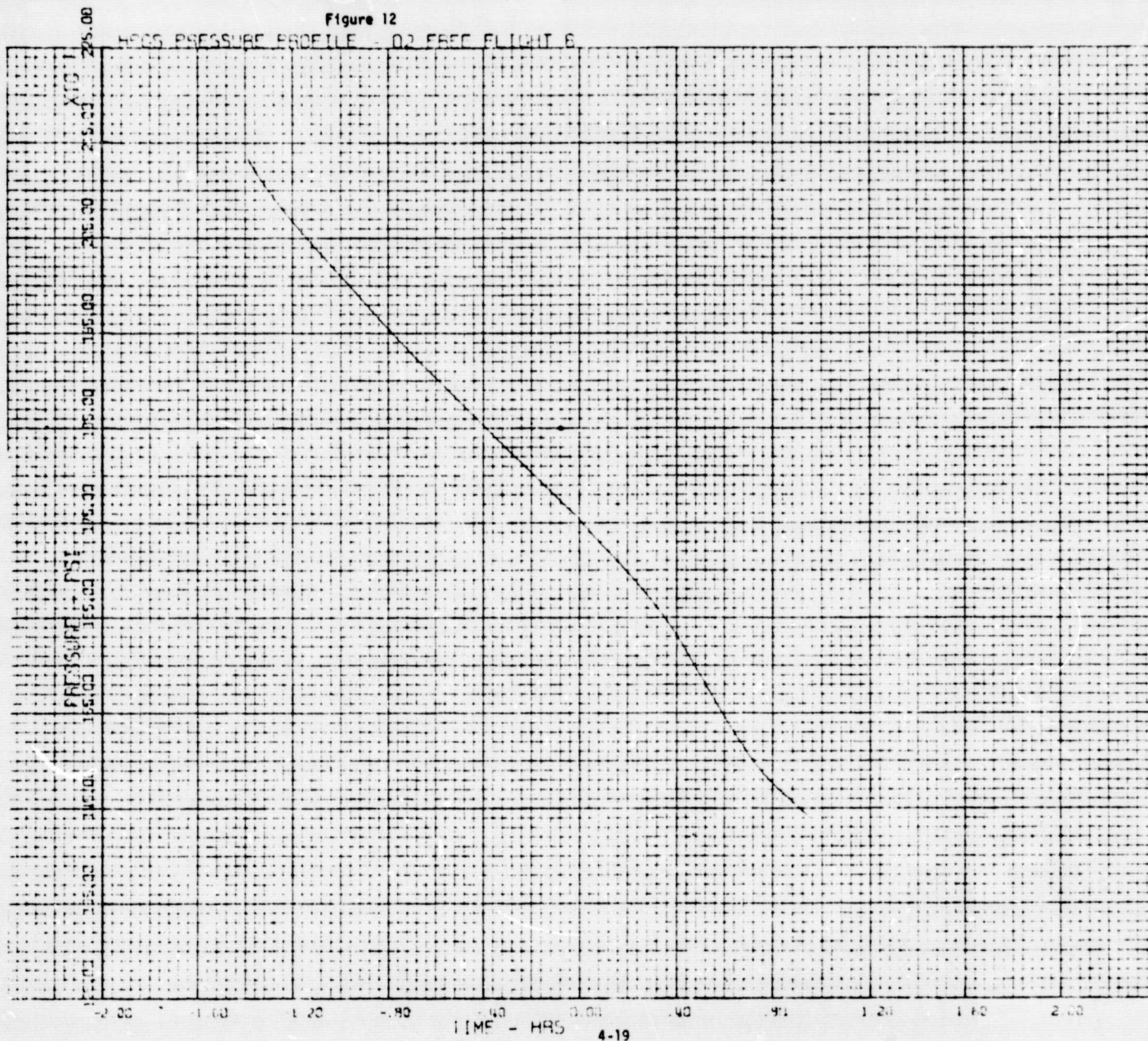




Figure 13

HQCS TEMPERATURE PROFILE - 02 FREE FLIGHT 6

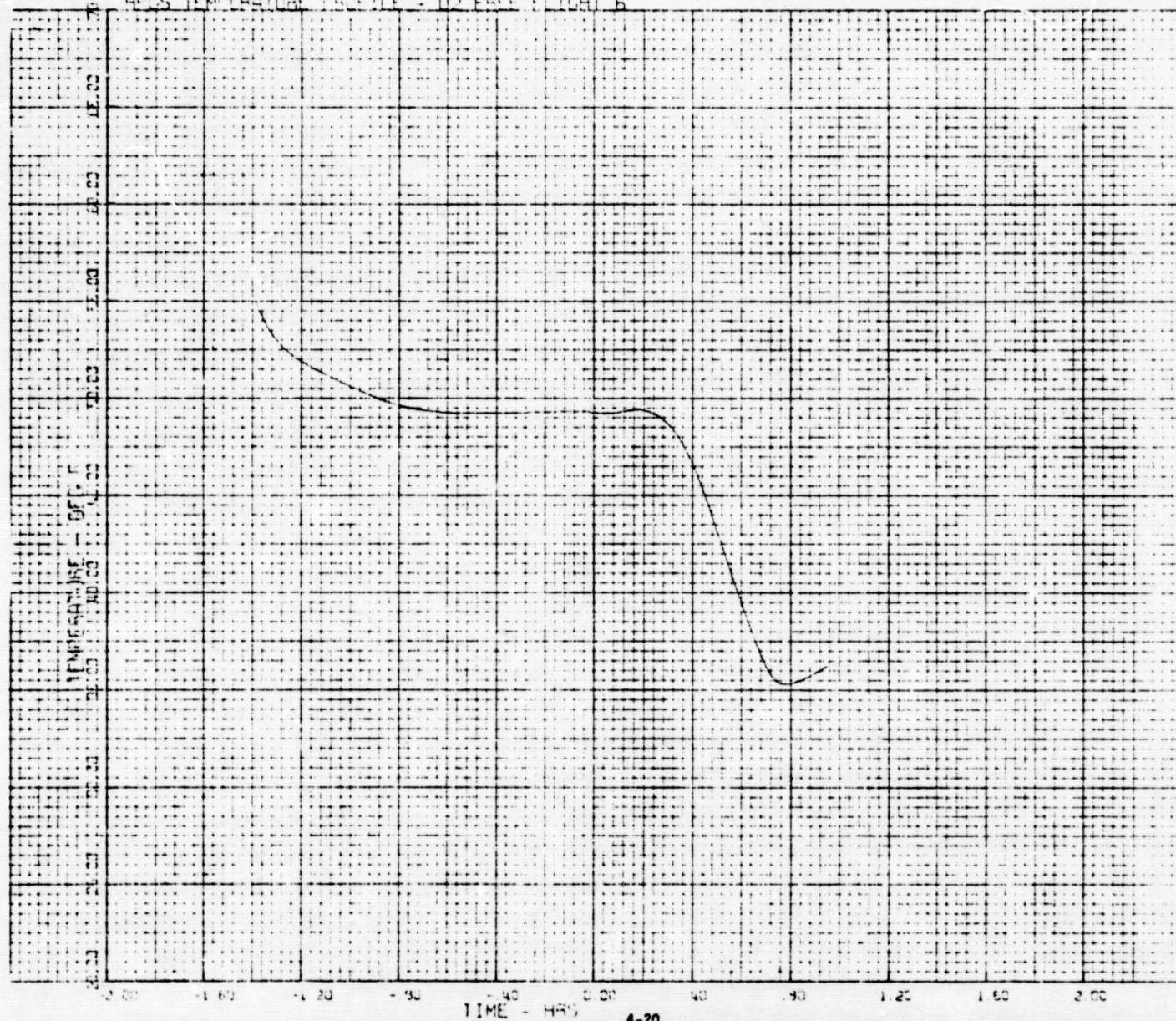
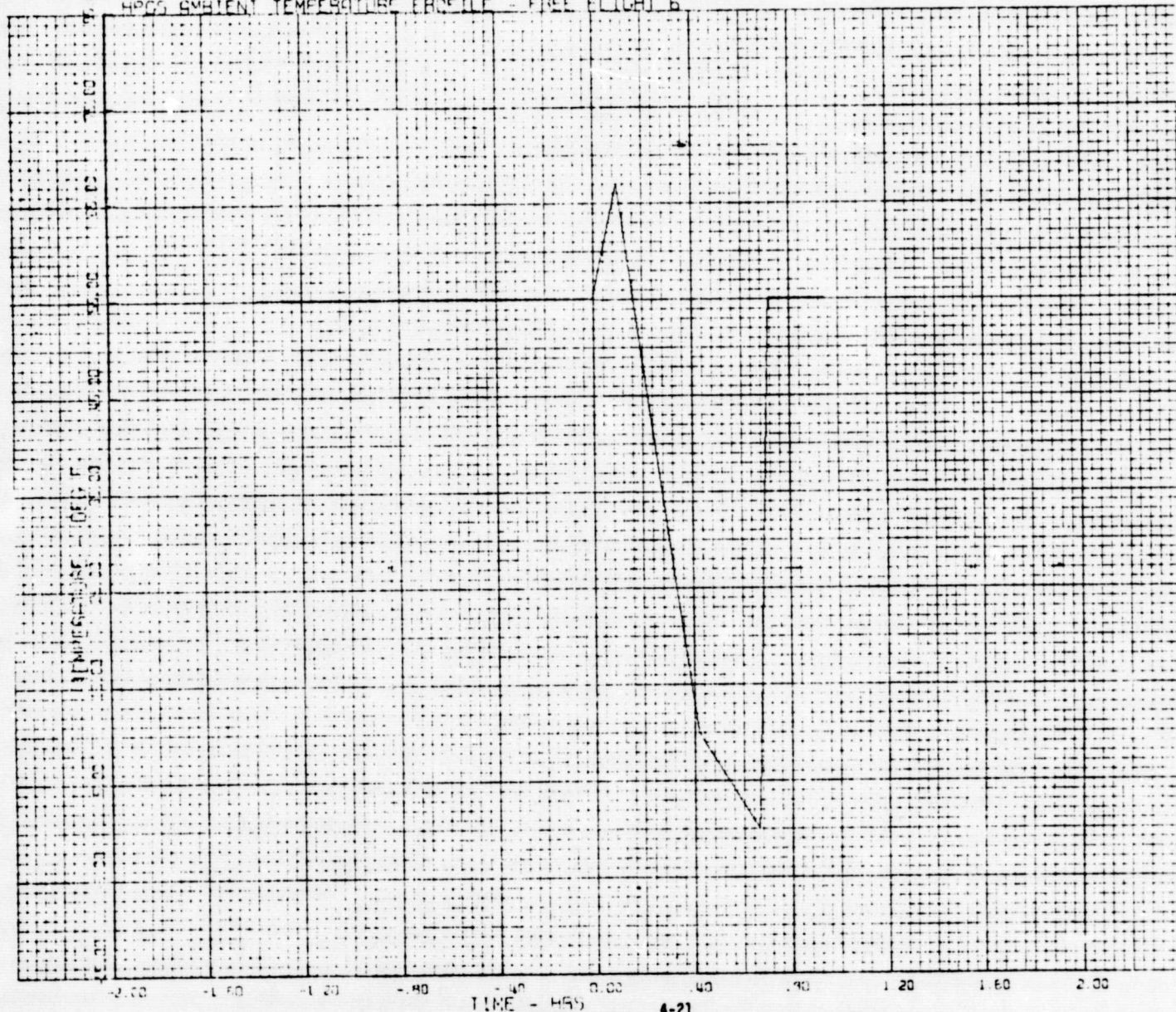


Figure 14

HPCG AMBIENT TEMPERATURE PROFILE - FREE FLIGHT 6



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